III. SUNSPOTS AND RAINFALL

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That original data of rainfall present an irregular and fortuitous appearance is well known. Rainstorms passing at a short distance from a dry observing station, erratic distribution of rain in cyclones, and the multitude of physical and geographical causes varying and influencing rainfall are well known. In central Texas, September 7 to 11, 1921, 4 inches of rain fell in 35 hours in one place and 23.98 inches was recorded only 18 miles away—a whole year's supply in three days.

This accidental distribution is a generally known fact. If, however, larger values of the elements of time and space are selected, a different picture appears. The writer has pointed out that the rain gage is virtually but a point in space and that run-off records do have a far more regular structure than rainfall records, probably because the integrating effect of large drainage areas offsets the added factors of seepage, transpiration, evaporation which influence run-off. This regular structure is a statistical fact, unassailable by theoretical considerations, which, indeed, rather should be based on such facts.

The accidental character of rain-gage data, while containing a large fortuitous element, is insufficient to obliterate the underlying trend. By proper statistical methods the underlying laws can be found, which are entirely invisible in the original data. Even the erratic rain gage will yield its secretly hidden periodic variations if treated with a proper method of analysis.

Nature provides the foundation of this analysis (integration) by collecting the precipitation in a vast drainage area and leading it into large storage basins. The variations in lake level are, in fact, the first integral of the precipitation, and, as hereby the longer cycles are increased, and the shorter suppressed in amplitude, these variations reveal unmistakably the succession of wet and dry periods. The famous terraces of Lake Bonneville and the periodic filling and depletion of the lake have been carefully studied (1). The Great Salt Lake rose 9½ feet between 1860 and 1877, fell 11½ feet between 1877 and 1905, and has risen 7 feet since then. The level in the Great Lakes was lowest in 1819, 0.5 foot lower than in 1925; it rose 6.6 feet from 1819 to 1838; both record stages occurring long before the Chicago drainage canal or the Soo Locks or the Gut Dam were made or the Detroit River was dredged (2).

Presumably, then, there is no discussion as to the existence of such periodic variations, the question rather being *to what extent* such variations are apparently fortuitous or, on the other hand, seem to be subject to cross-identification with other known phenomena of nature.

In the tangled skein of natural phenomena indications of periodic recurrences have long since been found, and their correlation has been a subject of prolonged and searching investigation. The periodic variations of rainfall have been carefully studied by Hellman (3), Brückner (4), Jenkin (5), Moore (6), Brooks (7), Abbé Gabriel (8), Schokalsky (9), Hann (10), Stockman (11), and many others. A discussion of such changes may be found in the works on climatology or physical geography, as Huntington and Visher (12) or Élisée Reclus (13). They are an accepted fact and can no longer be doubted.

It is now 37 years ago that Professor Eduard Brückner, geographer at the University of Berne, Switzerland, published his famous work, "Klimaschwankungen seit 1700." Herein the variations of rainfall are studied by means of

meteorological records and also through the historical records of the variations of lake levels, which, for many lakes and inland seas of the old world, reach far back into history. Brückner concluded, from these and many other elaborate statistics, that three variable cycles in climate exist, superimposed on each other, the shortest of which is now called the "Brückner cycle."

Such studies are being pursued up to the present day; one of the latest publications on lake levels as a means of forecasting rainfall being the study of Axel Wallén, "Zwölf Jahre langfristiger Prognosen von Niederschlag und Wasserstand" (19).
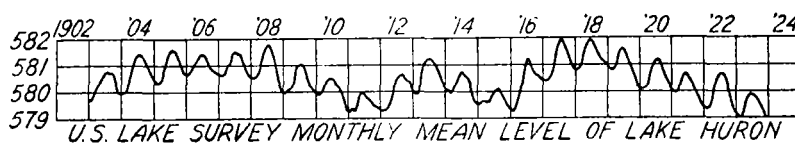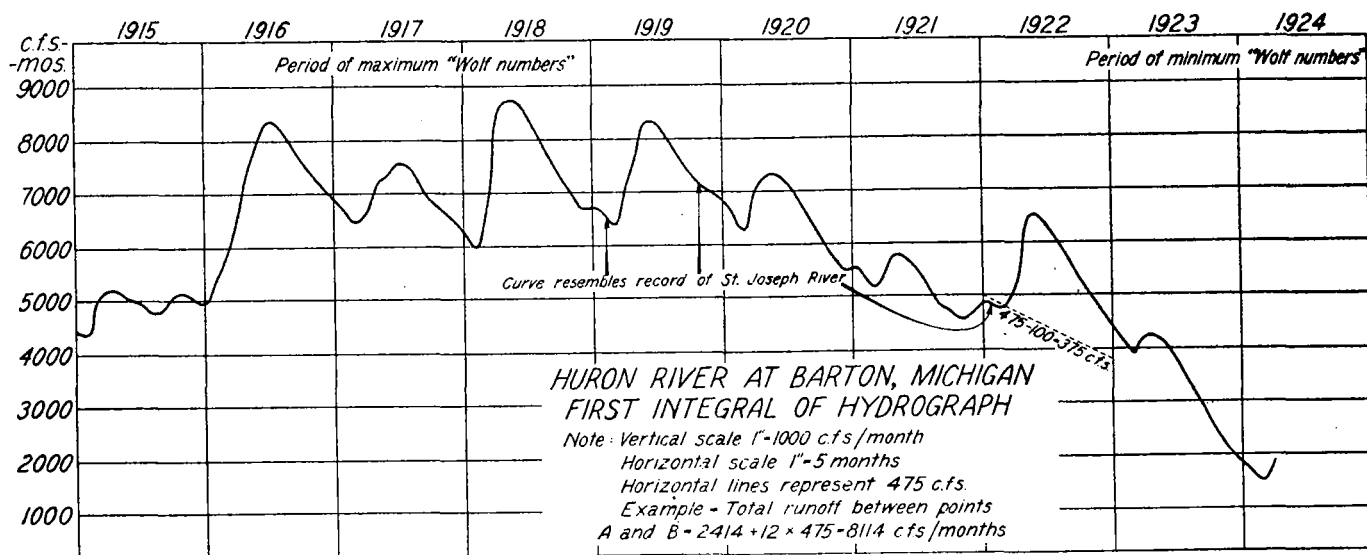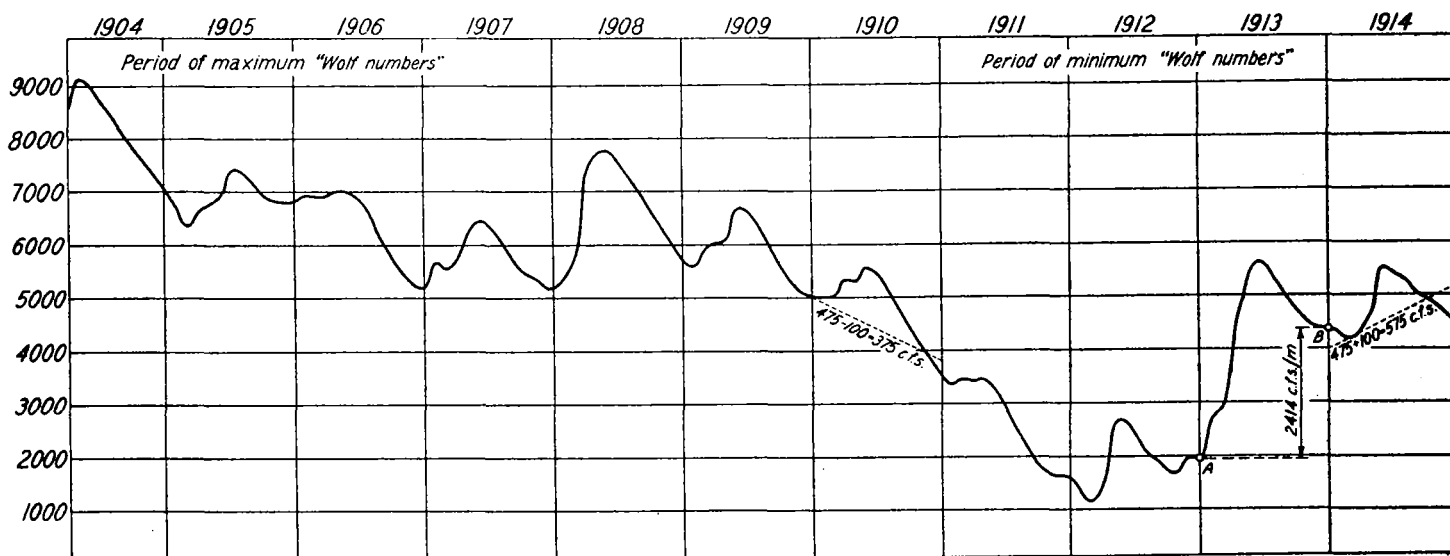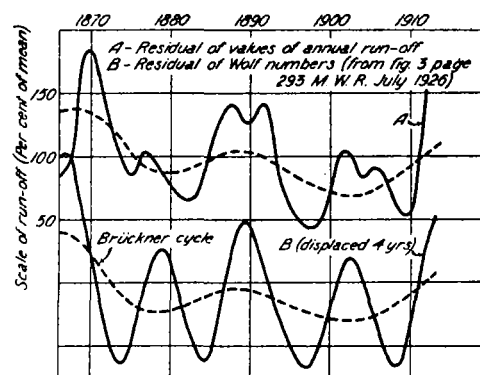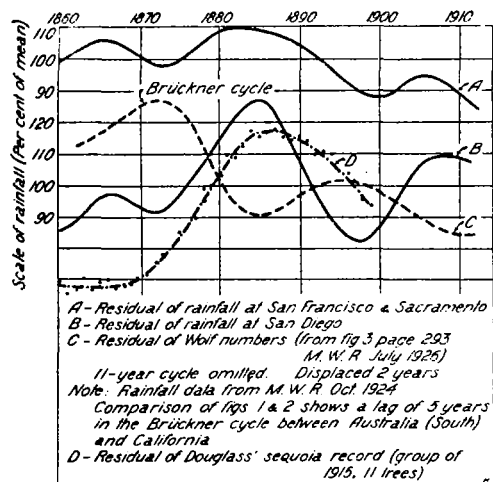
It is evident that in order to successfully support the theory that cycles in rainfall are illusory, the critic faces the task of pointing out errors in the statistics of these scientific investigators. Mere presentation of curves of original data having a fortuitous appearance seems insufficient. Original data always do present a fortuitous appearance. So did those used by the writer; the cyclic elements can of course only be found by means of proper methods of analysis, and the article here discussed was written principally to demonstrate certain methods by means of which correlations apparently were easily found.

The next question is whether the cycles in rainfall are in any way related to the Wolf numbers. This, too, has been the subject of many investigations. Sir Gilbert Walker (14), Buchan (15), Schreiber (16), Koenig (17), have studied the matter carefully. C. E. P. Brooks (18) published striking graphs for Victoria Nyanza in equatorial Africa which show the correlation clearly. These studies deal with the 11-year cycle.

The Brückner cycle, though unquestionably established, remained a detached fact unrelated with any known phenomenon of nature. Professor Brückner, searching for a plausible explanation of the climatic cycle, devoted a chapter of his book to the comparison with the Wolf numbers, but arrives at a negative result. Indeed, it appears that the climatic cycle is not related to the 11-year cycle, but if a mass curve is made of the Wolf numbers the relation of the Brückner cycle to the *long swing* in the Wolf numbers becomes immediately visible.

This perhaps is the solution of the riddle of the Brückner cycle; it seems identical with the long swing in the Wolf numbers or, more accurately, with the second largest cyclic element in the Wolf numbers. It is readily admitted, however, that for a proper scientific proof of the relation a vast array of statistical evidence must be given, such as furnished by Brückner to establish the climatic cycle.

On the other hand, in order to disprove the relation it will be necessary to furnish reliable data in which the Brückner cycle can not be found. The data of rainfall at San Diego and San Francisco and Sacramento are not proper material for this purpose, for these records show (see graph on p. 70) not only the cycle, but also that in spite of the large accidental differences from year to year in the rainfall of central California and southern California, as shown in the above discussion, the two records show the Brückner cycle in *practically the same phase*. And it is also shown that the cycle is nearly opposite in phase to the same cycle in the Wolf numbers, while in the East it has the same phase in rainfall and Wolf numbers.

A - Residual of rainfall at San Francisco & Sacramento
B - Residual of rainfall at San Diego
C - Residual of Wolf numbers (from fig 3 page 293
    M. W. R. July 1926)
   11-year cycle omitted.   Displaced 2 years
Note: Rainfall data from M. W. R. Oct. 1924
    Comparison of figs 1 & 2 shows a lag of 5 years
    in the Brückner cycle between Australia (South)
    and California
D - Residual of Douglass' sequoia record (group of
         1915, 11 trees)

A - Residual of values of annual run-off
B - Residual of Wolf numbers (from fig 3 page
    293 M. W. R. July 1926)

Period of maximum "Wolf numbers"
Period of minimum "Wolf numbers"

Curve resembles record of St. Joseph River

HURON RIVER AT BARTON, MICHIGAN
FIRST INTEGRAL OF HYDROGRAPH
Note: Vertical scale 1"=1000 c.f.s/month
      Horizontal scale 1"=5 months
      Horizontal lines represent 475 c.f.s.
      Example = Total runoff between points
      A and B = 2414 ÷ 12 × 475 = 8114 c.f.s/months

U.S. LAKE SURVEY MONTHLY MEAN LEVEL OF LAKE HURON

It may further be seen that the variation due to the Brückner cycle has considerable amplitude, although the curves shown are residuals and do not give the full amplitude, the amplitude of the residual at San Diego is not less than 35% of the mean for the epoch shown. Also, this residual (San Diego) seems to coincide with the residual of Douglass' sequoia record (1915, 11 trees).

Other investigators have found a relation between San Diego rainfall and sun spots. Mr. John R. Freeman writes: "Three years ago, when studying on the water supply for the city of San Diego, I became perfectly convinced that in that region there was a connection between the Wolf sun-spot cycle and the great floods which have come, about once in 10 years, ever since the earliest days of the Spanish missions."

Taking another quarter of the globe, the writer also presents (p. 70, top) a residual of the run-off of the Murray River, one of the largest drainage basins of Australia, the record of which was obtained through the courtesy of Mr. Elwood Mead. The relation is here again visible, and the Brückner cycle in run-off differs about six years in phase between South Australia and California.

For the Middle West the relation with the Wolf numbers is plainly visible. The mass curve of the Huron River at Barton, Mich., obtained by the writer through the courtesy of Mr. Gardner S. Williams, shows the relation with the 11-year cycle; also the secondary maximum at sun-spot minimum already pointed out by Hann (21). This is still better visible in the level of Lake Huron, the fall in level after 1913 (sun-spot minimum) being accentuated probably by evaporation and not so plainly visible in the river record.

Through all ages and in various regions of the globe the relation is traceable. G. del Valle (22) presents interesting graphs of the long rainfall record of the ancient university city of Padua in the Po Valley and the high-water stages of the River Nile from 1725 to date, which reveal immediately the agreement with the two long swings of the "secular cycle." (Fig. 1, p. 292, MONTHLY WEATHER REVIEW, July, 1926.) The historic record of the high and low water stages of the Nile, A. D. 642 to 1451, given by Aboul Mahasin in the "Mémoires de l'Institute d'Egypte, 1923," covering a period of eight centuries, unmistakably shows the tendency of run-off to follow a periodic variation, having, according to Del Valle, a period of 210 years. Unfortunately the record of the Wolf numbers is too short to permit a comparison.

It seems quite possible that the total yearly rainfall taken over the whole globe should vary from year to year in spite of the nearly constant amount of heat received yearly from the sun. Evaporation is dependent on humidity as well as temperature, and on other factors as well—as, for instance, exposed surface area and wind velocity. Evaporation will take place in a thermally isolated vessel without supply of heat, thereby lowering the temperature. The latent heat is always restored to the atmosphere upon condensation, and possibly is used repeatedly, as in industrial multiple evaporators. Perhaps the findings of Doctor Dorno, tending to prove (20) increased atmospheric condensation (circumpolarer Gegenschein) with increasing sun spots, furnish a plausible explanation of the relation between rainfall and sun spots. However, the relation of Wolf numbers and terrestrial phenomena is, as Doctor Marvin expresses it, full of interminable perplexities, and undoubtedly contains many physical elements thus far wholly unexplained.

Statistical evidence can always be classified as merely accidental until it becomes available in such large quan-

tity that the reality of the relation can no longer be doubted. On the other hand, unless reliable records are offered in which this relation can not be found by analysis, it seems unfounded to regard the mere fortuitous appearance of the original data as sufficient proof of the absence of a relation between sun spots and rainfall.

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